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(54) Modifying power density of a laser beam shaper

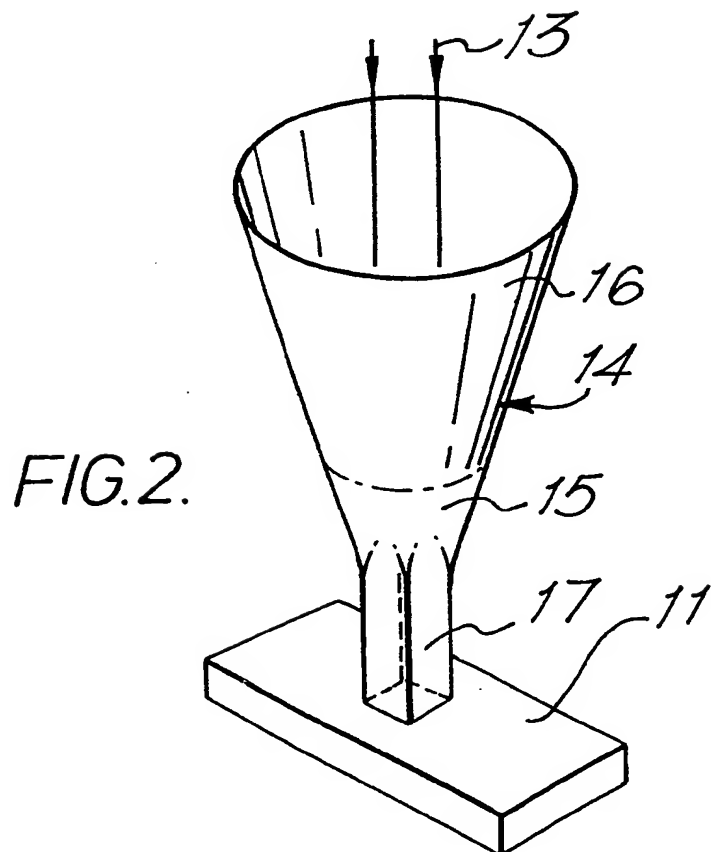
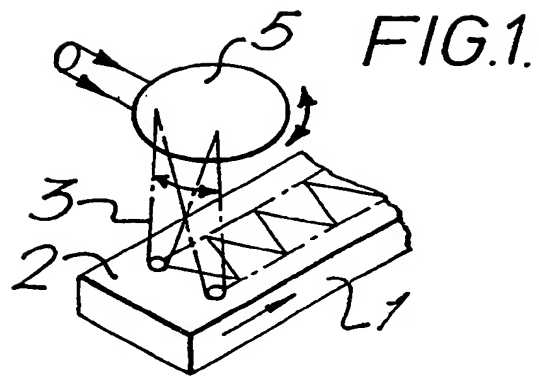
(57) A beam shaper is combined with a laser to provide a laser beam having a substantially uniform power density over a predetermined area at the surface of a workpiece to be surface hardened. The beam shaper is hollow and open at opposite ends. The internal surface of the beam shaper is capable of reflecting the laser beam passing through it so that on exit from the shaper the beam has a predetermined uniform density.

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SPECIFICATION

Heat treatment by laser beam

- 5 The surface of a workpiece made of carbon steel, alloy steel or cast iron can be transformation hardened by heating the surface by means of a laser beam above a critical temperature and rapidly cooling by self quenching when the beam has been removed from the surface. The fast cooling caused by heat conduction from the heated surface to the cold interior of the metal causes hardening of a thin surface layer through metallurgical transformation of austenite to martensite or a matrix of martensite and bainite.

This method of surface hardening by laser beam offers the advantage over furnace or induction hardening that localised heating is possible and no separate quench is necessary. Thus, laser heat treatment offers a saving in that post heat treatment processes such as straightening and machining are unnecessary. Furthermore, in laser heat treatment less heat is used for a shorter time thereby eliminating or at least minimising the possibility of heat distortion of the workpiece. It is known for laser heat treated parts often to be placed directly on a final assembly line thereby eliminating costly grinding and honing operations.

- However, the beam emanating from a laser is usually circular in cross-section and may have a non-uniform distribution of power, for example, a Gaussian distribution. If a circular section beam is traversed over the area of the workpiece to be heat treated, then the time at temperature across the heat treated area at right angles to the traverse direction will not be constant. The lateral extremities of the area will have a short time at temperature compared to the central zone of the area. Further, if the power density is not uniform then some parts of the workpiece may be overheated and melted whilst others may not be heated sufficiently to result in transformation hardening. This results in inefficient utilisation of the laser energy because the heat treatment conditions cannot be optimised across the heat treated zone. In practice, this will cause the depth of the hardened layer to vary over the width of the area being irradiated by the beam. At the centre, the hardened layer will be deep relative to the flanks or lateral extremities of the area. In an attempt to overcome this disadvantage when only a Gaussian beam is available it is known to employ a scanning or zig-zag method. This known scanning method requires a focused beam and then scanning the area selected for heat treatment transverse to the direction of the surface or beam traverse by means of oscillating mirrors. If the scanning is effected two or more times at high speed, it causes a heating effect on the surface of the workpiece similar to a rectangular distributed heat source. The zig-zag system is flexible in that the shape of the rectangular distribution can be altered simply by altering the oscillation of the mirrors. This feature is useful in particular for research purposes. However, the apparatus necessary for the implementation of the zig-zag system is expensive and hot spots or lines can occur on the

surface being treated. Furthermore, difficulties have arisen in maintaining the precise location of the scanned area due to optical lever effects.

- According to one aspect of the present invention, a laser apparatus is combined with a hollow beam shaper open at opposite ends and having an internal surface capable of reflecting the beam when it emanates from the laser and passes therethrough, the distribution of the beam on exit from the beam shaper having a substantially predetermined uniform density over a predetermined area.

According to a further aspect of the present invention, a method of providing a laser beam of substantially uniform power density at a surface of a workpiece over a predetermined area comprises passing a laser beam of a given distribution through a hollow beam shaper open at opposite ends and having an internal surface capable of reflecting at least once light of the wavelength passing there-through, the distribution of the beam on exit from the beam shaper having a substantially predetermined uniform density over a predetermined area.

- An embodiment of the invention will now be described by way of example, reference being made to the Figures of the accompanying diagrammatic drawings in which:

Figure 1 is a schematic perspective view of a laser beam being used in the known scanning or zig-zag method to heat treat a surface of a workpiece; and *Figure 2* is a schematic perspective view of a hollow beam shaper.

Figure 1 shows a workpiece 1 having a surface 2 a portion of which is being subjected to irradiation by a laser beam 3. In contrast to welding and cutting operations which require a highly focused beam, when surface hardening a workpiece the beam should have a generally rectangular area in the order of 1 cm square for a 2 KW power level and with a high degree of uniform power density. This is achieved in the known scanning method illustrated in *Figure 1* by locating the workpiece 1 at the focal point of the scanning mirror. To obtain a uniform power density at the surface 2 the beam is scanned rapidly by a means of an oscillating mirror 5 backwards and forwards across the surface of the portion being heat treated in a direction transverse to the direction of movement of the workpiece 1 relative to the beam 3. A scanning mirror can be incorporated to give a scan parallel to the direction of movement of the workpiece 1 relative to the beam 3.

This known method is useful particularly for research in view of its flexibility, that is, the shape of the scanned area can be altered quickly as required by adjusting the oscillations of the mirrors. However, the provision of the mirrors and the motors for oscillating the mirrors is expensive. Furthermore, with this method it has been known for hot spots or hot lines to occur on the surface being treated and difficulties have been experienced in maintaining the precise location of the scanned area due to optical lever effects.

Figure 2 illustrates a laser beam 13 emitted from a CO₂ laser (not shown) having an intensity distribution which is substantially Gaussian, which beam is

passed through a hollow beam shaper 14 open at opposite ends. The beam shaper 14 is made of copper and is gold plated on its inner surface in order to reflect efficiently light at a wavelength of 10.6 microns, that is the wavelength of light emitted from a CO₂ laser.

The beam shaper 14 comprises a generally conical part 16 for receiving the beam 13 emitted from the laser, a transition part 15 and a rectangular exit throat 17.

A workpiece 11 is positioned on a carriage (not shown) so that it is capable of moving under the beam emitted from the beam shaper 14 via the exit throat 17.

In operation, the laser beam 13 is reflected at least once as it passes through the beam shaper 14 and the effect is to produce at the surface of the workpiece as it passes under the beam shaper 14 a rectangular area of substantially uniform power density.

An example of heat treatment by laser beam will now be given. A 2 Kilowatt CO₂ laser emitting a beam of 30 millimetre diameter and having a Gaussian power distribution was used in combination with a hollow beam shaper made of polished copper. The conical part of the beam shaper had a length of 70 millimetres with an open free end diameter of 40 millimetres. The transition part had a length of 15 millimetres and the exit throat a length of 40 millimetres. The exit throat was rectangular in cross-section and had dimensions 9 millimetres by 6 millimetres.

The workpiece was of EN19 steel including 0.4 carbon, 1.2 chromium and 0.6 molybdenum (British Standard 970) coated with colloidal graphite. The workpiece was traversed in a direction parallel to the 6 millimetres exit throat dimension at a speed of 10 millimetres per second. The gap between the free end of the exit throat and the surface of the workpiece to be hardened was 3 millimetres.

The hardened layer on the workpiece had a depth greater than or equal to 0.5 millimetre and the width of the hardened layer was 8 millimetres. The hardened layer had a hardness value of 600 VPN.

It will be appreciated that the angle of the conical part will be determined by the beam diameter and the distribution exit throat dimensions. In this respect the beam shaper need not have a conical part but a part of rectangular section.

It will be clear that the beam shaper can be made of other materials provided they reflect efficiently light of the wavelength being passed through them. Furthermore, if different shaped areas having a uniform power density are required then different beam shapers may be necessary. This may appear at first glance to be expensive but since the beam shapers are simple pieces of formed material then they are extremely cheap to manufacture. For workpieces having a complex shape then it is possible that two or even more beam shapers may be necessary to heat treat a particular portion of than workpiece. The beam shaper can be fabricated from several parts which can be detached one from another for cleaning and polishing. In this respect the exit throat can be made detachable from the

remainder of the beam shaper so that different exit throats can be used with only one remaining part.

The beam shaper may be provided with a jacket for cooling fluid or with heat transfer finning on its outer surface.

A particular advantage in using a laser in combination with the beam shaper is that the precise positioning of the workpiece surface at the focus of the laser beam is unnecessary and in fact there is a wide tolerance in the region of 1 cm in which the surface of the workpiece to be treated can be placed relative to the end of the beam shaper.

The embodiment illustrated in Figure 2 offers the following advantages over the known scanning or zig-zag method illustrated in Figure 1:

- (a) it is far cheaper to produce one or more beam shapers than it is to provide the mirror system and vibrators;
- (b) there is no need for a precise positioning of the surface to be heat treated relative to the beam emanating from the beam shaper;
- (c) a plurality of beam shapers can be used for any particular job to permit the heat treatment of complex surface shapes;
- (d) there is substantially no chance of inadvertent forming hot spots or lines, and
- (e) it is robust.

Although reference has been made to the shaping of a laser beam having a Gaussian intensity distribution, it is possible that a laser beam having a "top hat" distribution can be shaped in the manner described above.

In the embodiment described above reference has been made to transformation hardening. It is envisaged that the method of beam shaping could also be used in other types of heat treatment such as the melting of alloys or chemicals into the surface of a workpiece to obtain particular surface properties.

105 CLAIMS

1. A laser apparatus combined with a hollow beam shaper open at opposite ends and having an internal surface capable of reflecting the beam when it emanates from the laser and passes therethrough, the distribution of the beam on exit from the beam shaper having a substantially predetermined uniform density over a predetermined area.

2. The combination claimed in claim 1, in which the beam shaper has a conical part for receiving the beam emitted from the laser, a transition part and a rectangular exit throat from which the beam leaves the beam shaper with a substantially predetermined uniform density.

3. The combination as claimed in claim 1 or 2, in which the beam shaper is made of copper and is gold plated on its inner surface.

4. The combination as claimed in any one of claims 1, 2 or 3, in which the beam shaper is made from several parts which are detachable one from another.

5. The combination as claimed in any one of claims 1 to 4, in which the beam shaper is provided with heat transfer finning on its outer surface.

6. The combination as claimed in any one of

claims 1 to 4, in which the beam shaper is provided with a jacket for cooling fluid.

7. A method of providing a laser beam of substantially uniform power density at a surface of a workpiece over a predetermined area comprising passing a laser beam of a given distribution through a hollow beam shaper open at opposite ends and having an internal surface capable of reflecting at least once light of the wavelength passing there-
10 through, the distribution of the beam on exit from the beam shaper having a substantially predetermined uniform density over a predetermined area.

8. A laser apparatus combined with a hollow beam shaper substantially as hereinbefore described with reference to and as illustrated in Figure
15 2 of the accompanying drawings.

9. A method of providing a laser beam of substantially uniform power density at a surface of a workpiece substantially as hereinbefore described
20 with reference to Figure 2 of the accompanying drawings.

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